TRANSONIC AERODYNAMIC AND BUFFET CHARACTERISTICS OF A PACKAGED SPACE STATION IN COMBINATION WITH A SATURN V LAUNCH VEHICLE

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SUMMARY

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A wind-tunnel investigation has been conducted to determine the transonic aerodynamic and buffet-pressure characteristics of a launch configuration model of a packaged, manned orbital space station in combination with a modified Saturn V launch vehicle. The tests were conducted at Mach numbers from 0.50 to 1.20 and over a range of angles of attack from -6° to 16°.

The results of this investigation indicate that the aerodynamic characteristics of the complete vehicle were not significantly affected by the presence of the packaged space station. The normal-force and axial-force contributions of the packaged space station were approximately 55 percent of the total over the Mach number range. The largest buffet pressures measured on the packaged space station were only about 10 percent of the free-stream dynamic pressure.

Author

INTRODUCTION

Recent wind-tunnel studies (ref. 1) have indicated that local aerodynamic loads on a space vehicle can be critical at transonic speeds. Also, the aerodynamic loads associated with buffeting can impose many problems on a space vehicle (ref. 2) as it accelerates through the transonic speed range. The presence of unsteady shock-boundary-layer interactions in the flow around the vehicles has led to the suggestion that buffeting loads may have caused several space vehicles to fail during the transonic and low-supersonic range of their exit trajectories.

Therefore, as a part of the research efforts of the NASA Langley Research Center on the manned orbital space station, a wind-tunnel investigation has been conducted in the Langley 8-foot transonic pressure tunnel to determine the aerodynamic and buffet characteristics of a launch configuration model of a manned orbital space station in combination with a modified Saturn V launch vehicle. The primary purpose of the investigation was to provide experimental data for structural design purposes, trajectory analyses, and stability and control studies.

In order to obtain the static aerodynamic data, measurements were made with an internally mounted tandem-dual force-balance system on a 0.9-percent-scale model of the packaged space station in combination with the Saturn V launch vehicle. Buffet pressures were measured along the packaged space station by means of dynamic-pressure transducers. The investigation was conducted at Mach numbers from 0.50 to 1.20, angles of attack from -6° to 16°, and Reynolds numbers per foot from 1.75×10^6 to 2.76×10^6.

SYMBOLS

The forces and moments measured on both the packaged space station and the complete vehicle were referred to the body system of coordinate axes with the origin for the packaged space station located at the base of the space station. The origin for the complete vehicle was located at the base of the Saturn V launch vehicle. Coefficients for both the packaged space station and the complete vehicle are based on the same reference area and diameter. The coefficients and symbols used herein are defined as follows:

A — cross-sectional area of 0.9-percent-scale model of Saturn V launch vehicle, 0.0693 sq ft

C_N — normal-force coefficient, $\frac{\text{Normal force}}{qA}$

C_A — axial-force coefficient, $\frac{\text{Axial force}}{qA}$

$C_{A,\alpha=0}$ — axial-force coefficient at $\alpha \approx 0^\circ$

$C_{A,b}$ — base-axial-force coefficient, $\frac{\text{Base axial force}}{qA}$

$C_{A,c}$ — cavity-axial-force coefficient, $\frac{\text{Cavity axial force}}{qA}$

C_m — pitching-moment coefficient, $\frac{\text{Pitching moment}}{qAd}$

C_{N_α} — normal-force-curve slope at $\alpha \approx 0^\circ$, $\frac{\partial C_N}{\partial \alpha}$, per deg

C_{m_α} — pitching-moment-curve slope (measured near $\alpha = 0^\circ$), $\frac{\partial C_m}{\partial \alpha}$, per deg

$\Delta C_{p,rms}$	root-mean-square of buffet-pressure coefficients, σ/q
d	diameter of 0.9-percent-scale model of Saturn V launch vehicle, 0.2966 ft
l	length of packaged space station, 1.311 ft
M	free-stream Mach number
q	free-stream dynamic pressure, lb/sq ft
r	radius, in.
R	Reynolds number per foot
$\frac{x_{cp}}{d}$	location of center of pressure in body diameters forward of the launch-vehicle base
x	distance along packaged space station measured from tip of launch escape tower, in.
α	angle of attack, deg
σ	root-mean-square of pressure fluctuations, lb/sq ft
Φ	power spectral density, $\frac{(\text{lb/sq ft})^2}{\text{cps}}$

TUNNEL

The Langley 8-foot transonic pressure tunnel, which was used for this investigation, is a single-return type with a rectangular test section. The upper and lower walls are slotted longitudinally to allow continuous operation through the transonic speed range with negligible effects of choking and blockage. Stagnation pressures can be controlled from approximately 1/4 to 2 atmospheres. During the tests, automatic temperature controls maintained a constant stagnation temperature of 120° F. In order to prevent condensation shocks, the dewpoint temperature was maintained near 0° F. Design of the sting-support system is such that the model remains near the center line of the test section throughout the angle-of-attack range.

MODEL DESCRIPTION

Tests were performed with a 0.9-percent-scale, launch-configuration model of a manned orbital space station in combination with a modified (minus third stage) Saturn V launch vehicle. Drawings and photographs of the model showing pertinent dimensions are shown in figures 1 to 4. The modules of the packaged space station were attached to a 45° cone at the rearward end and were shielded at the forward end by a body with a 35° flare angle. The modules were directly exposed to the airstream; and although the air could not pass directly through from one side of the model to the other, it could flow around and under the modules. Cross sections of the space-station model and the full-scale design are shown in figure 5. The difference between the two was necessitated by the installation of the forward strain-gage balance in the model. The forward end of the packaged space station consisted of a launch-escape system with the Apollo spacecraft.

TESTS AND ACCURACY

Tests were conducted in the Langley 8-foot transonic pressure tunnel over a Mach number range from 0.50 to 1.20 and through an angle-of-attack range from -6° to 16°. In order to provide the desired angle-of-attack range and remain within maximum balance load limitations, all the data except at a Mach number of 0.50 were obtained at a free-stream total pressure of 0.50 atmosphere. Data at a Mach number of 0.50 were obtained at a total pressure of 1.0 atmosphere. The variation of test Reynolds number per foot with Mach number is shown in figure 6.

The estimated accuracies of the measured coefficients based on instrument calibration and data repeatability are within the following limits:

	M = 0.50	M = 1.20
Coefficients measured by the rearward balance:		
C_N	±0.069	±0.049
C_A	±0.023	±0.016
C_m	±0.051	±0.037
Coefficients measured by the forward balance:		
C_N	±0.037	±0.026
C_A	±0.014	±0.010
C_m	±0.010	±0.007

The variation of the actual test Mach numbers from the presented nominal values is approximately ±0.003. Model angles of attack are estimated to be accurate within $\pm 0.1^\circ$.

MEASUREMENTS, INSTRUMENTATION, AND PROCEDURES

Force and Moment Data

In order to measure the forces and moments on the packaged space station independently of those on the complete vehicle, a tandem-dual force-balance arrangement was used as shown in figure 1. Each strain-gage balance measured six-component forces and moments. The rearward balance measured the forces and moments acting over the entire vehicle, whereas the forward balance measured only the forces and moments acting on the packaged space station. The tandem-dual force-balance system necessitated a circumferential break or gap of 0.030 inch in the rigid external surface of the model between the base of the packaged space station and the forward end of the launch vehicle as shown in figure 2. In order to minimize any external aerodynamic influence due to the flow through the gap, a circumferential baffle was incorporated in the gap. Static pressures inside the model in the forward balance cavity, in the rearward balance cavity, and at the base of the model were also measured at each data point.

The axial-force coefficients derived directly from measurements made by both the forward and the rearward balances were influenced by the local external pressure at the circumferential gap between the space station and launch vehicle, and the pressures in the rearward balance cavity and at the model base. Therefore, axial-force data presented herein are both adjusted and unadjusted for the effects of internal-balance cavity pressures and model base pressure. The angles of attack presented are corrected for model sting and balance deflection due to aerodynamic forces and moments on the model. The effects of wind-tunnel boundary-reflected disturbances were negligible at all test Mach numbers except at 1.13 for the complete vehicle. For this reason, data on the complete vehicle at a Mach number of 1.13 are omitted.

Buffet Data

The buffet pressures along the top center line of the packaged space station were measured by means of six inductance-type dynamic-pressure transducers, located as shown in figure 1. The range of the pressure transducers used was ± 15 pounds per square inch and they were mounted as follows: one on the Apollo spacecraft, one slightly forward of the 35° flare angle, and four along the top center module. For each of the six transducers, a steady transducer reference pressure equal to the average local pressure (measured at same longitudinal station as transducer pressure) was insured by the use of a 50-foot tube length which provided sufficient damping of local pressure fluctuations due to separation, tunnel stream turbulence, or model vibration. Thus, each transducer measured the fluctuations in pressure about the average or mean static pressure. Other major electronic components used for both recording and analyzing buffet data from each pressure transducer are shown in a block diagram in figure 7. A more detailed description of the equipment and procedures used is given in reference 3.

At each data point during the buffet test, the mean-square value of the pressure fluctuations was continuously monitored through a thermocouple meter and printed out on strip charts. The mean-square values gave an indication of the buffet intensity, but did not provide the information necessary for investigation of the frequency characteristics. Therefore, a detailed time history of the random pressure fluctuations was simultaneously recorded on magnetic tape at all test points by using 45-second data samples. Power-spectral-density plots of the buffet response were derived from the magnetic tape through the use of the analog equipment described in reference 3. The data were analyzed in the frequency range from 0 to 600 cycles per second (approximate gage limit) by using an approximate 6.0-cycle-per-second band-pass filter and a 15-second tape loop.

Root-mean-square values of the random pressure fluctuations were obtained from the thermocouple data which were recorded on strip charts. In addition to values obtained from thermocouple data, root-mean-square values were also obtained by integrating the power-spectral-density data. However, the agreement between the two methods was poor. This disagreement was attributed to the fact that very little signal appeared above the internal noise level of the tape analyzer.

No attempt has been made to subtract any tare readings (with the exception of band-pass filtering) from the fluctuating-pressure data due to either wind-tunnel or instrumentation-induced noise levels. Calibrations of all the pressure transducers and tape-recorder channels were made before and after the buffet investigation in order to minimize the effects of small changes in the calibration constants. The tape recorder was calibrated with a 100-cps sine wave (root-mean-square voltage, 250 millivolts).

PRESENTATION OF RESULTS

The results of this investigation are presented in the following figures:

DISCUSSION

Basic Data

The basic force- and moment-coefficient data obtained on both the packaged space station and the complete vehicle are presented in figures 8 to 10. Since the data measured by both the forward and rearward balances are presented on the same plot, an indication of the percentage contribution of the packaged space station to the complete vehicle coefficients can readily be obtained. Also, an indication of the structural shear and moment loadings imposed at the point of separation between launch vehicle and space station can be obtained from examination of the forward-balance data.

Static Longitudinal Stability Characteristics

Presented in figure 8 are the curves of C_N plotted against α for both the packaged space station and the complete vehicle. Examination of the data in figure 8 indicates that the average normal-force contribution of the packaged space station was approximately 55 percent of the total normal force on the complete vehicle over the investigated Mach number range.

A summary of the static longitudinal stability characteristics of the packaged space station and of the complete vehicle is presented in figure 11. The variation of $\frac{x_{cp}}{d}$ for the packaged space station was negligible over the Mach number range; however, $\frac{x_{cp}}{d}$ for the complete vehicle moved rearward approximately one body diameter over the Mach number range.

Axial-Force Characteristics

A summary of the transonic axial-force characteristics of the packaged space station and the complete vehicle is presented in figure 12. The adjusted axial-force contribution of the packaged space station was approximately 55 percent of the total unadjusted axial force on the complete vehicle over the investigated Mach number range. The importance of base drag can be seen by noticing that the base-axial-force coefficients vary from approximately 35 percent to 50 percent of the axial-force coefficients for the complete vehicle over the Mach number range.

Buffet Characteristics

The variation of the root-mean-square of the buffet-pressure coefficients (determined from the thermocouple data) with angle of attack for the Mach number range is presented in figure 13. It is possible that the larger and more widely distributed values of the pressure coefficients at a Mach number of 0.50 were caused by the effects of increased test Reynolds number. Figure 14 shows the buffet pressure coefficients plotted streamwise along the packaged space station for four angles of attack and four Mach numbers. At transducers 1 and 2, the coefficients generally decrease with increasing angle of attack, but at transducers 3, 4, 5, and 6, the coefficients increase with increasing angle of attack.

Before experimentally determined pressure fluctuations can be applied in calculations to determine the response of a structure, properties of the fluctuations other than the root-mean-square intensities must be evaluated from the test results. Probably the most important of these is the power spectral density, which represents the variation with frequency of the mean-square value of the amplitude of the pressure fluctuations. Presented in figure 15 are sample power spectral densities for the model configuration investigated. As can be seen, the spectra are of the "white noise" type, that is, no predominant peaks.

The magnitudes of the presssure fluctuations varied from approximately 2.5 pounds per square foot to 30.2 pounds per square foot. For the transducer locations of this investigation, the largest value of the fluctuations was about 10 percent of the free-stream dynamic pressure on the basis of root-mean-square values, and is relatively small when compared with loads that have been measured on other launch-vehicle combinations (ref. 4). It should be cautioned, however, that because of the relatively low Reynolds numbers of the present investigation, and with the scaling relationships presented in reference 5, the results of the pressure-fluctuation measurements could be greatly altered when applied to a full-scale configuration.

CONCLUDING REMARKS

A wind-tunnel investigation has been conducted to determine the transonic aerodynamic and buffet-pressure characteristics of a launch-configuration model of a packaged, manned orbital space station in combination with a modified Saturn V launch vehicle. The tests were conducted at Mach numbers from 0.50 to 1.20 and over a range of angles of attack from -6° to 16°.

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Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 7, 1964.

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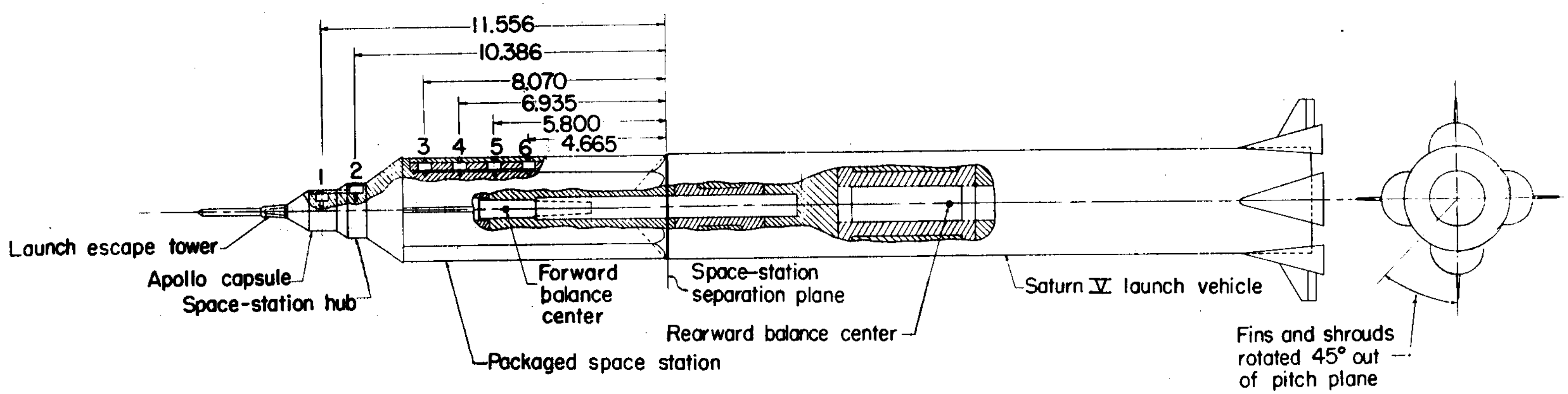


Figure 1.- Sketch of tandem-dual force-balance arrangement and locations of dynamic-pressure transducers. All dimensions are in inches unless otherwise noted.

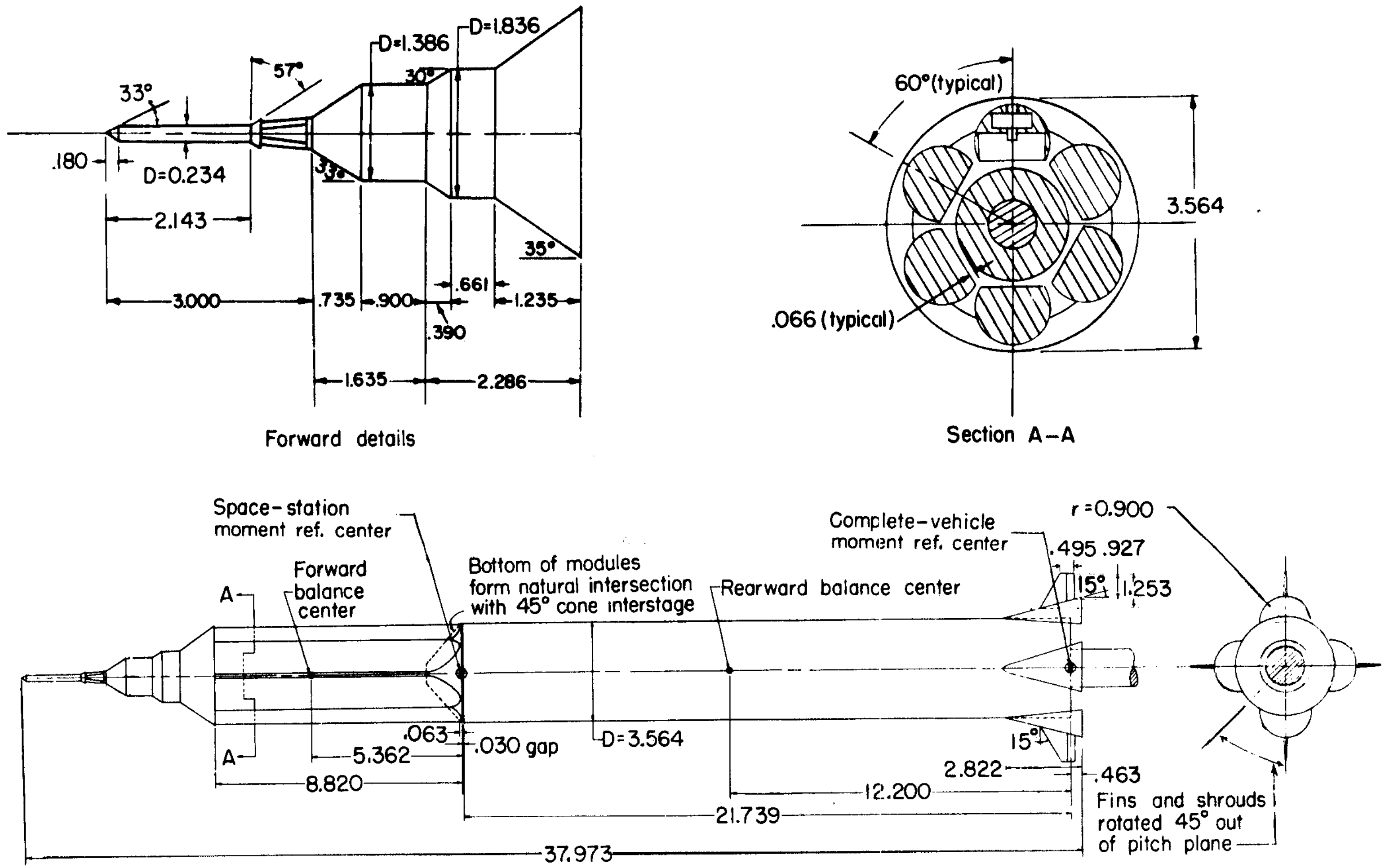


Figure 2.- Model geometrical details. All dimensions are in inches unless otherwise noted.

L-62-7901.1
Figure 3.- Photograph of complete vehicle installed in the Langley 8-foot transonic pressure tunnel.

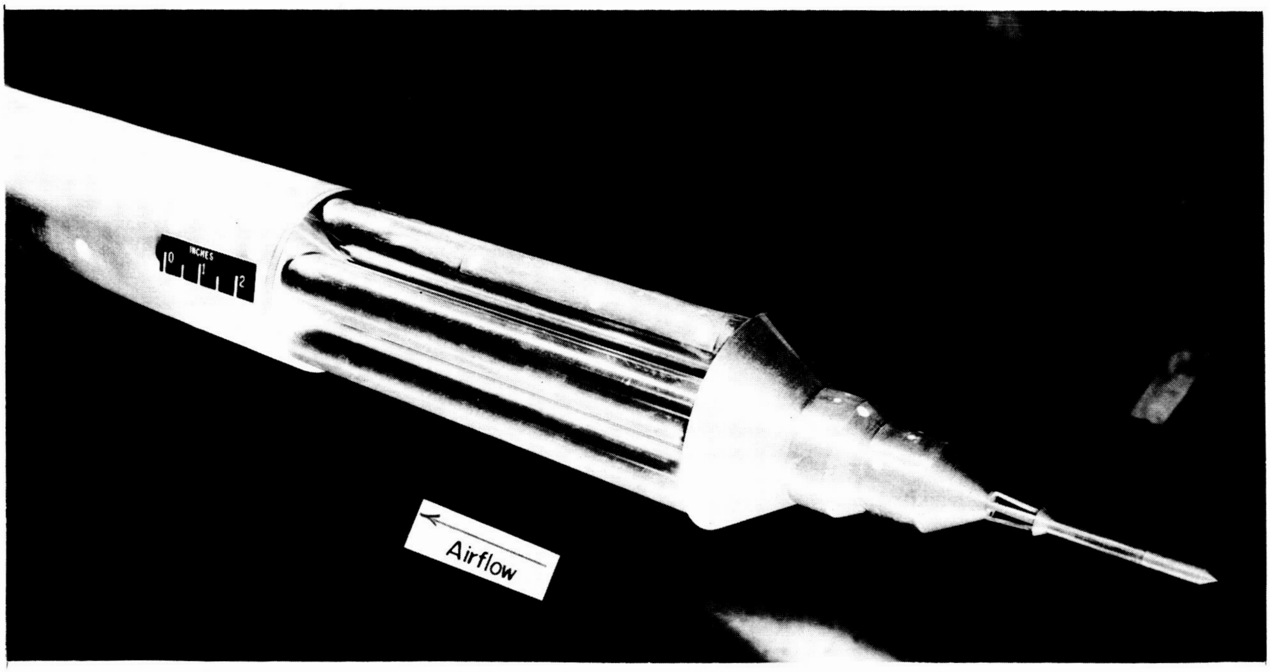


Figure 4.- Photograph showing packaged space station model details. L-62-7903.1

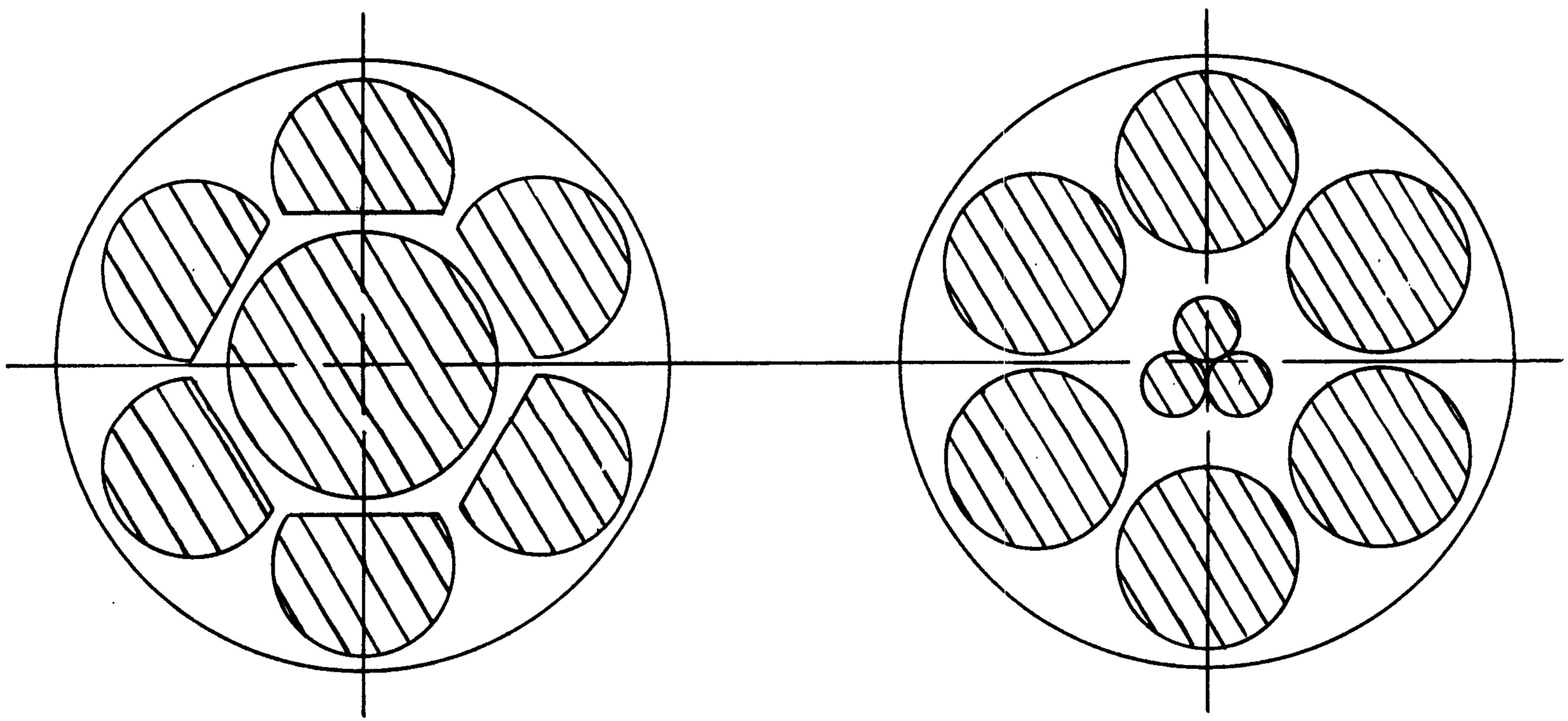


Figure 5.- Sectional views of packaged-space-station model and full-scale design.

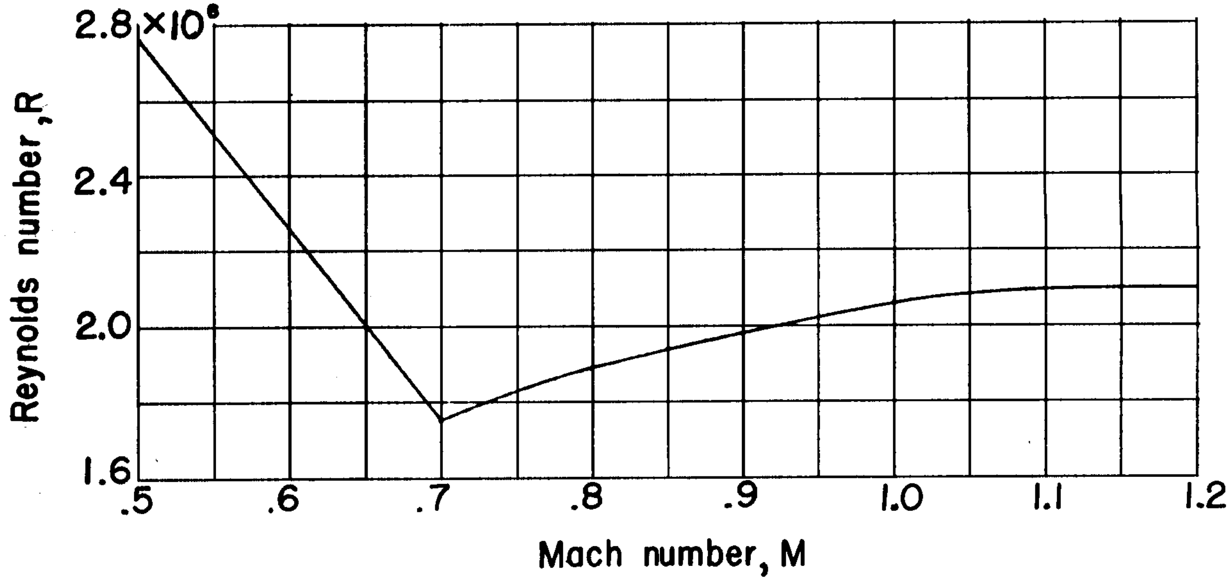


Figure 6.- Variation of test Reynolds number per foot with Mach number.

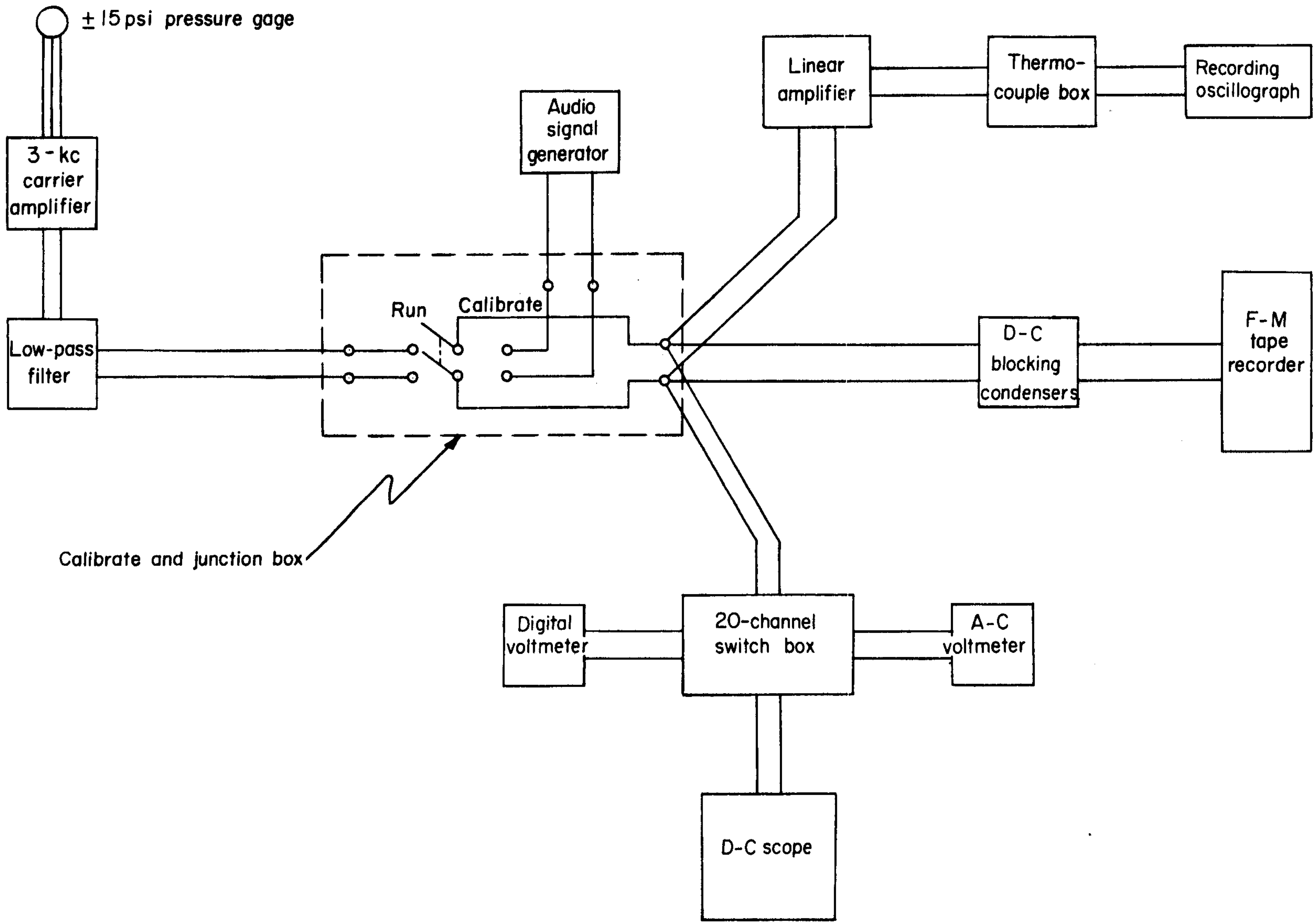


Figure 7.- Block diagram of instrumentation used to record buffet data. (Drawing shows one channel of six identical channels.)

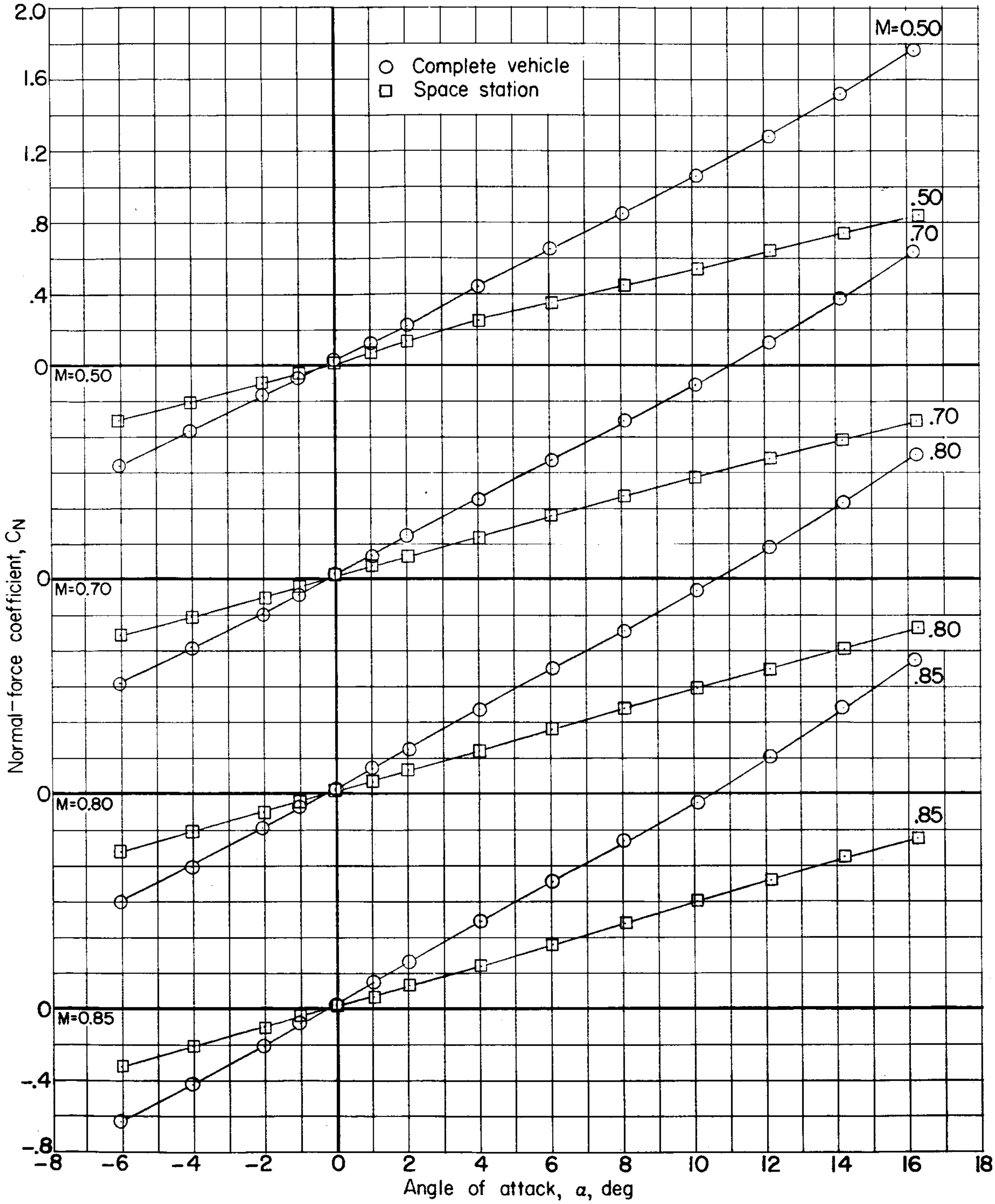
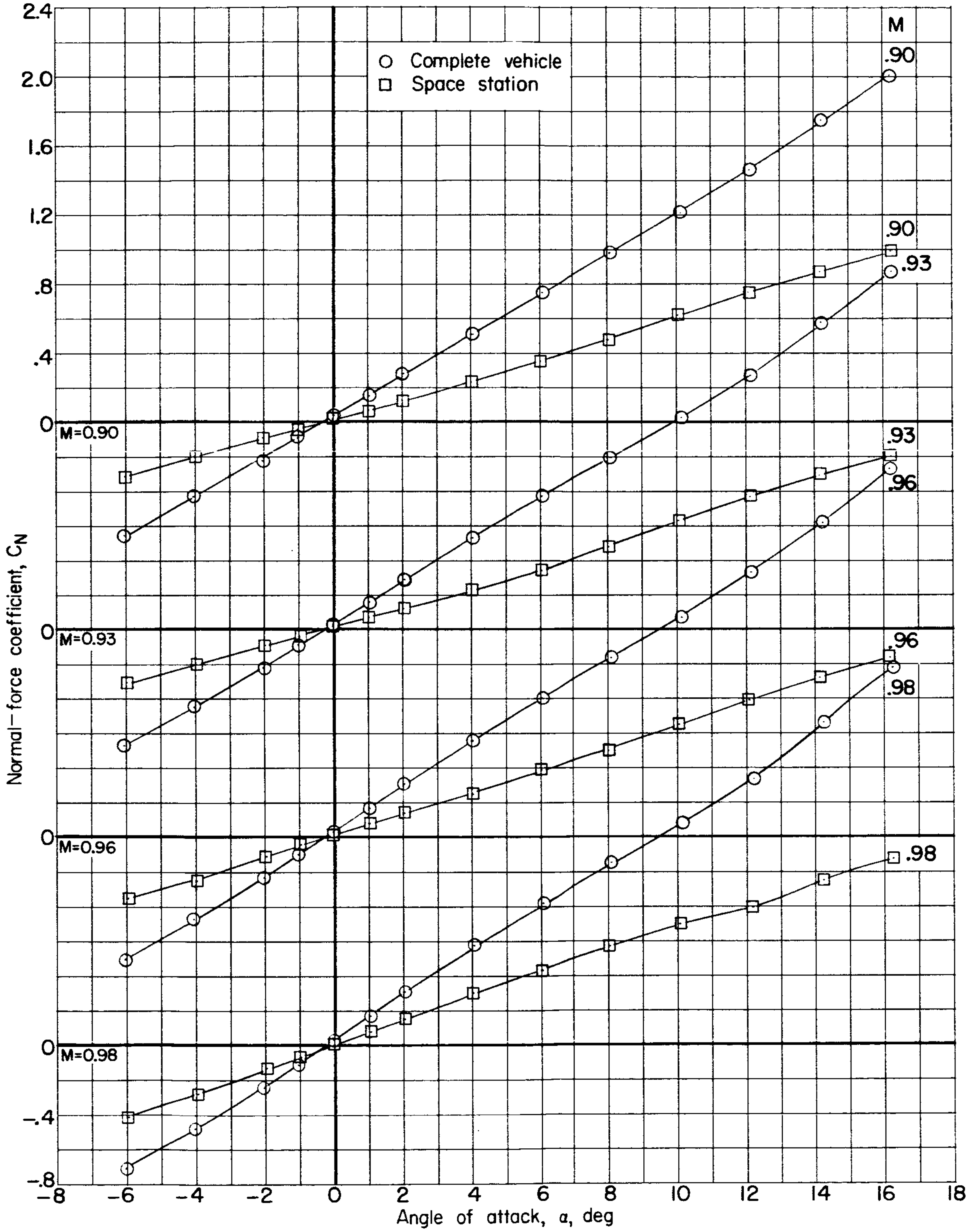


Figure 8.- Variation of normal-force coefficient with angle of attack.



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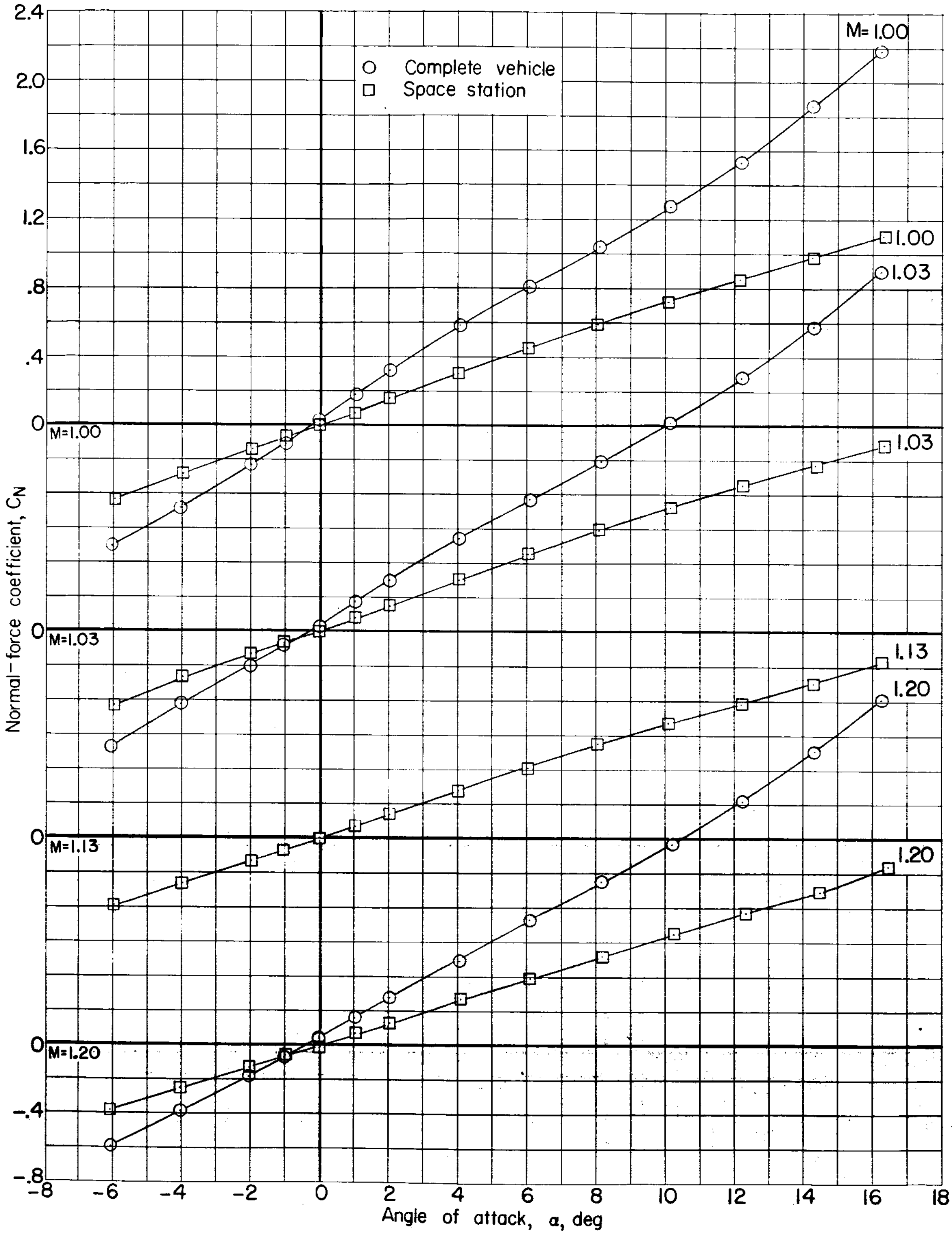

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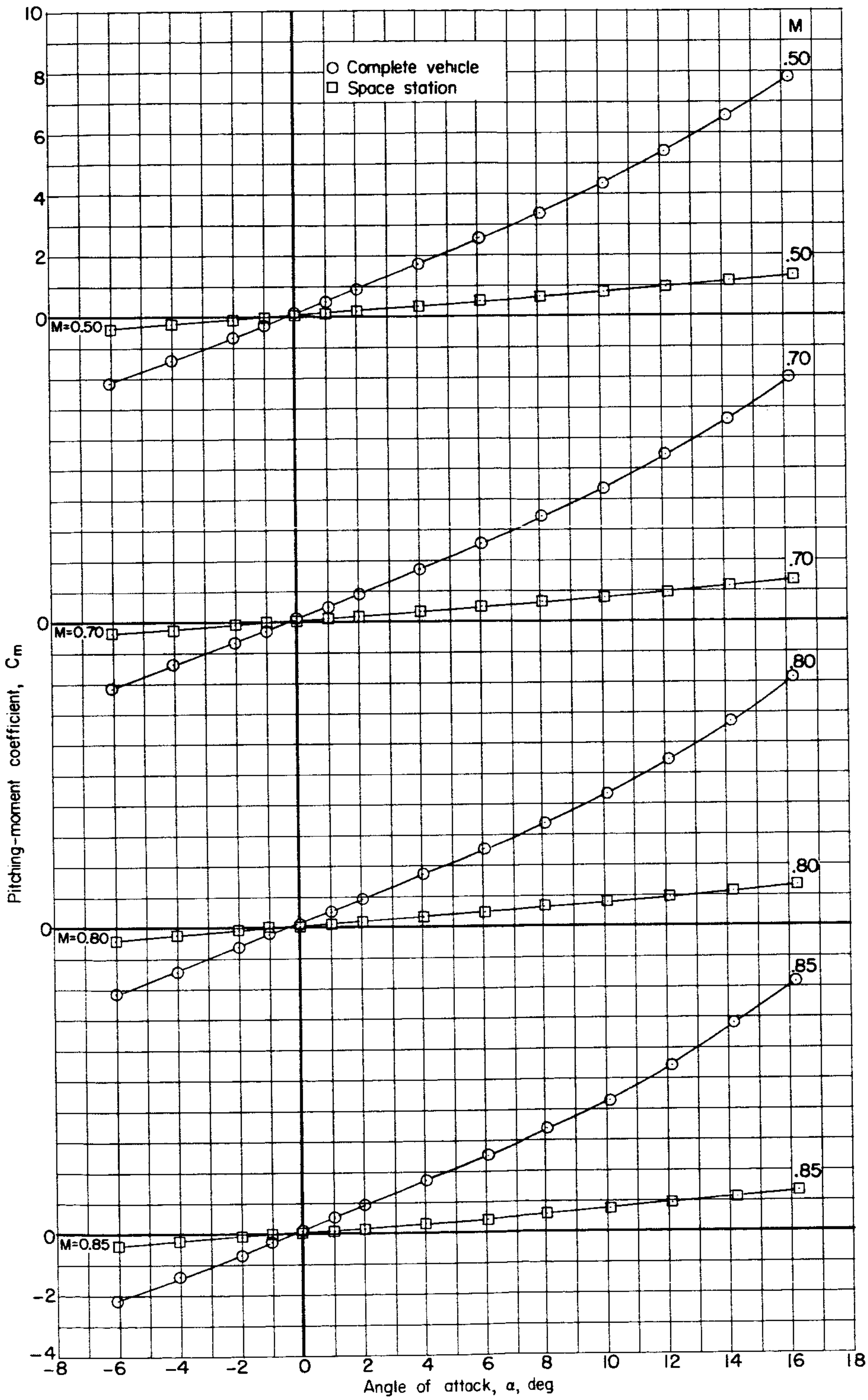
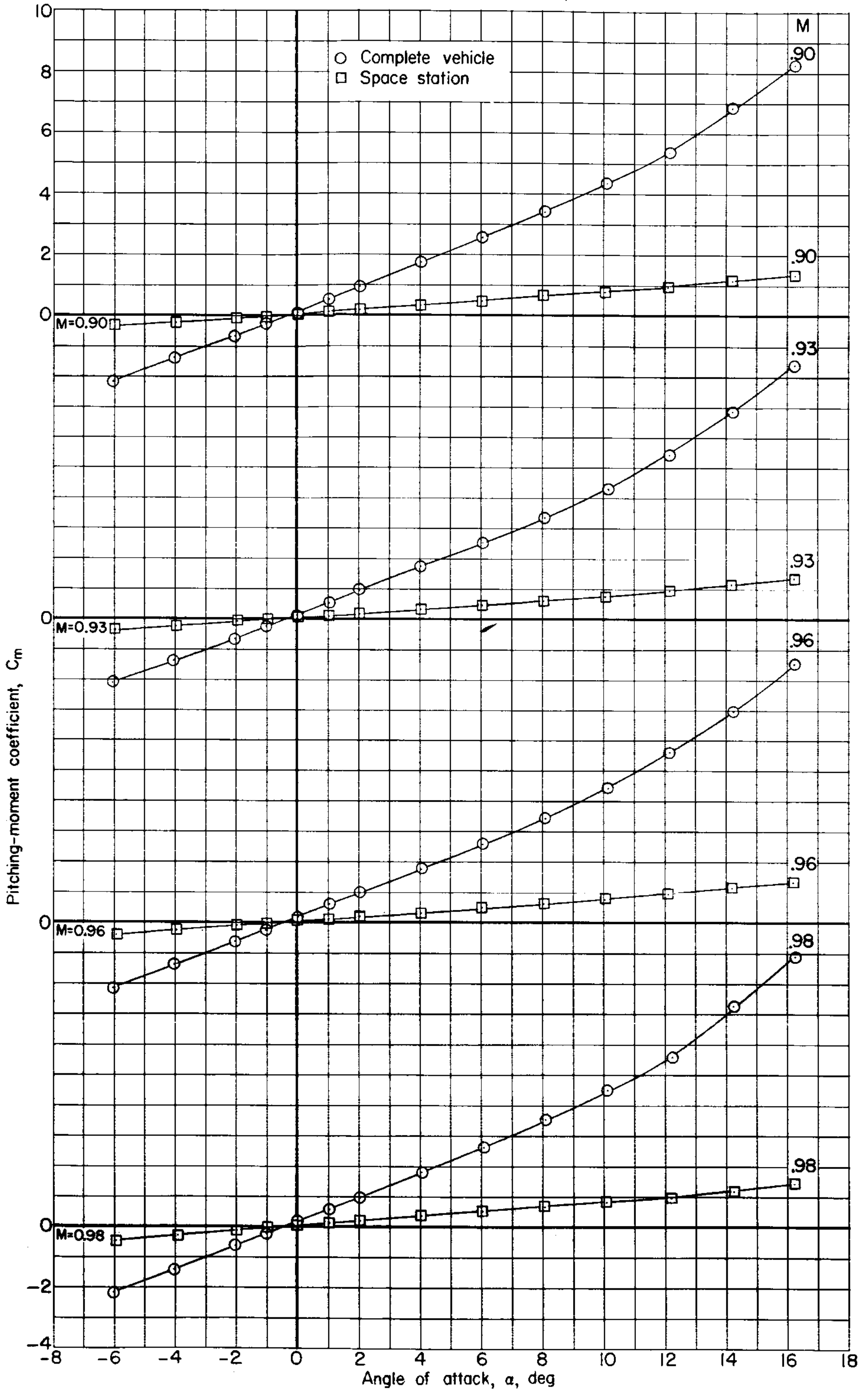


Figure 9.- Variation of pitching-moment coefficient with angle of attack.



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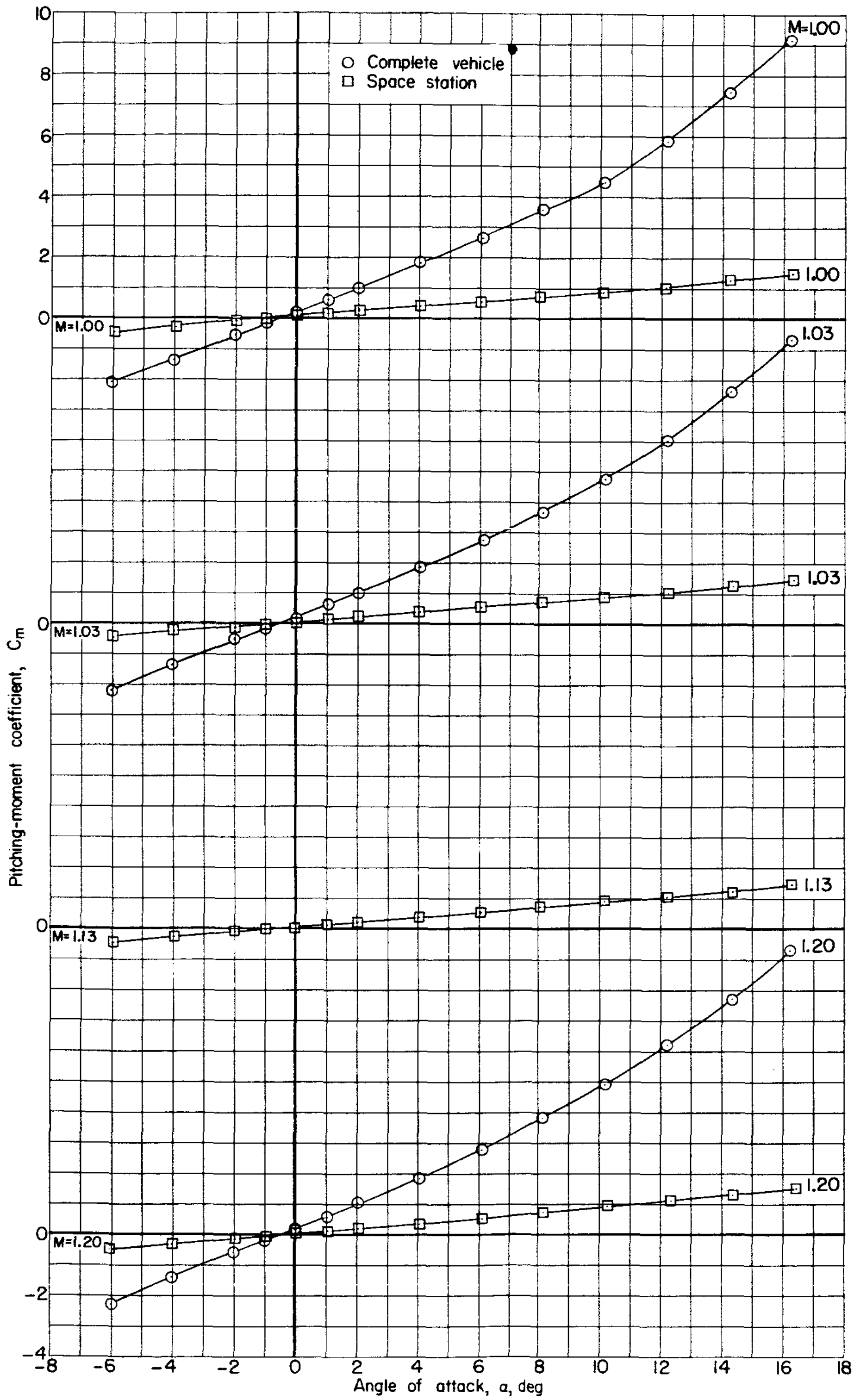

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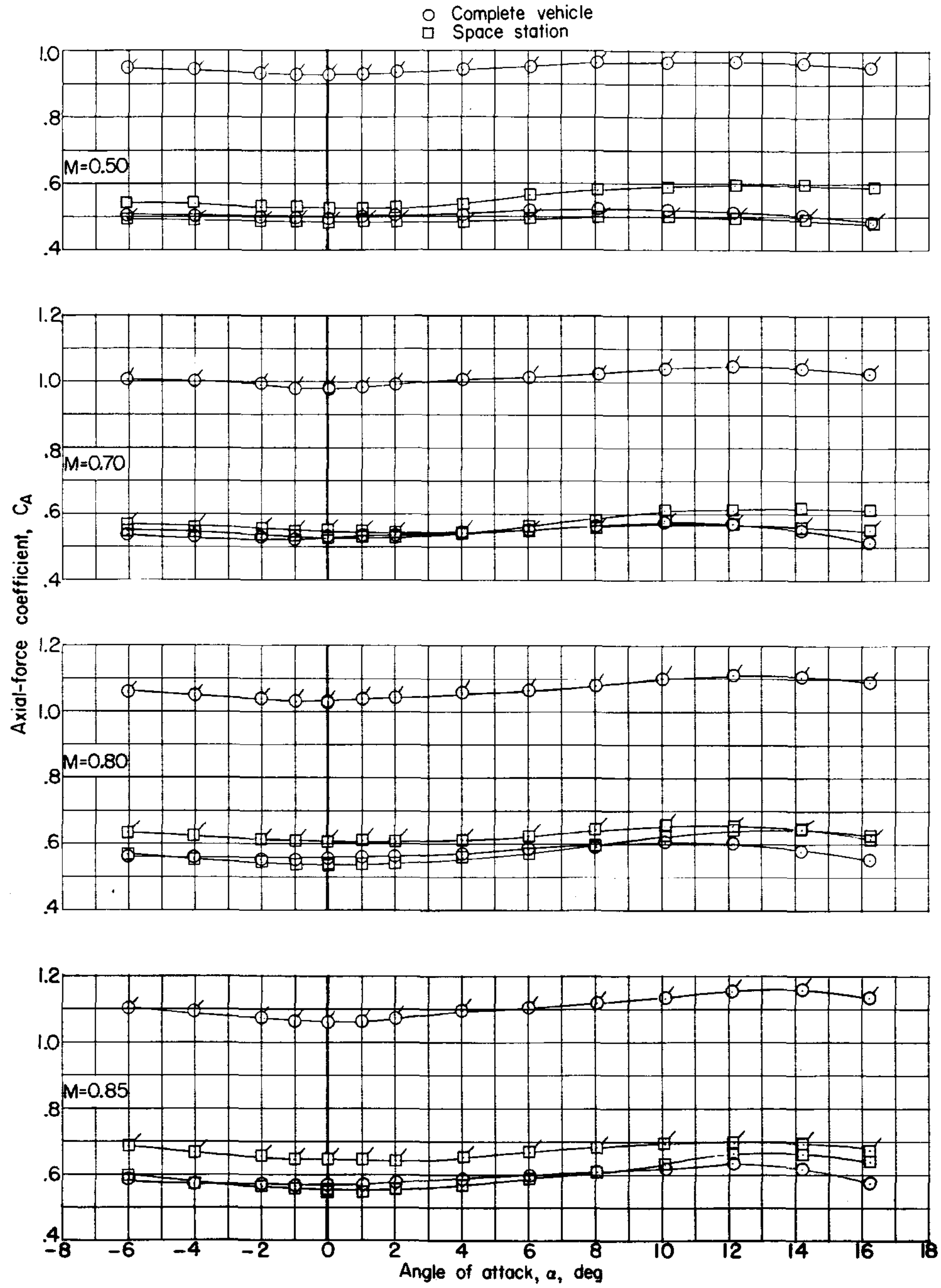
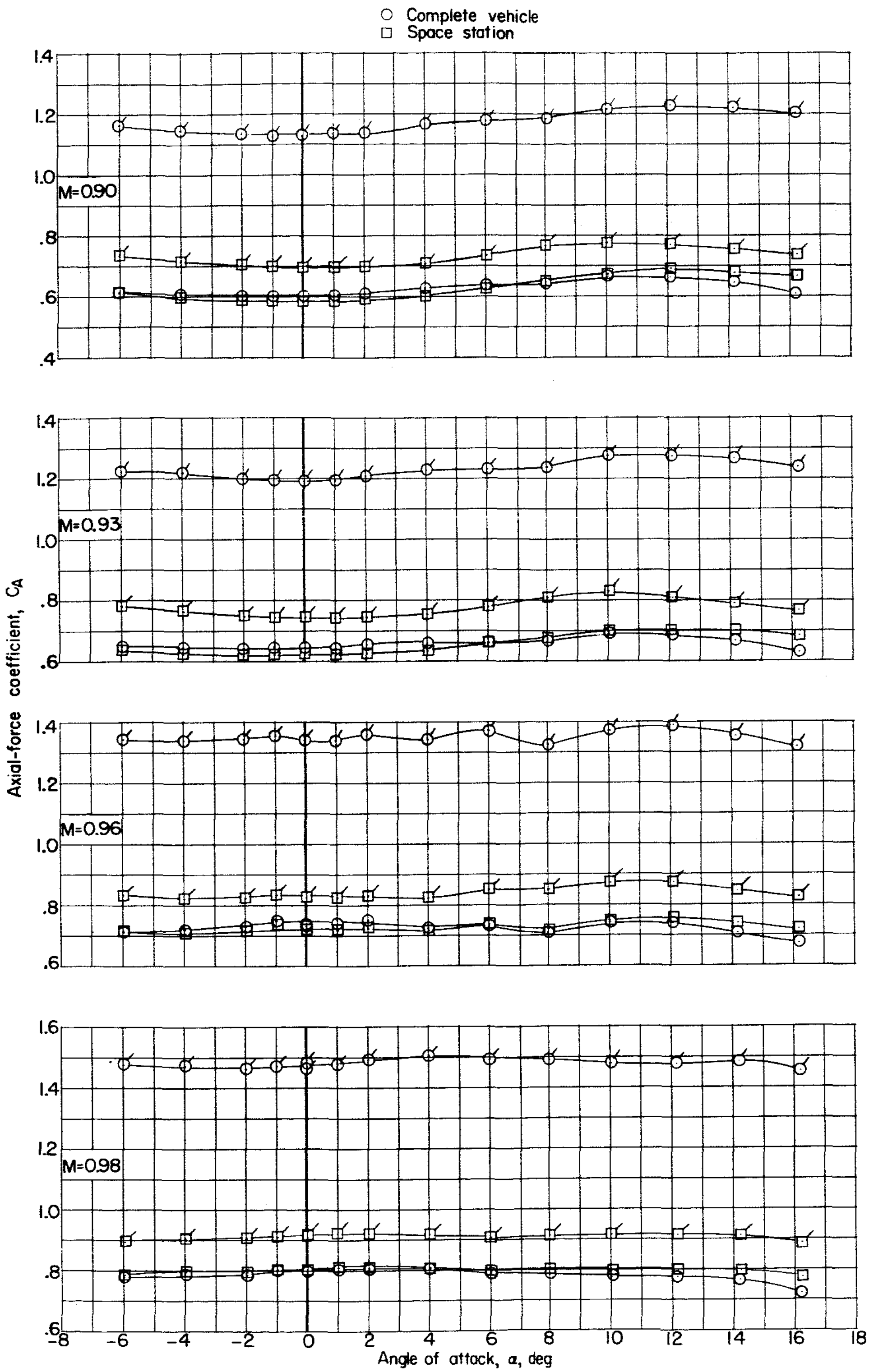


Figure 10.- Variation of adjusted and unadjusted axial-force coefficients with angle of attack. Flagged symbols indicate data are unadjusted for balance-cavity and model-base pressures.



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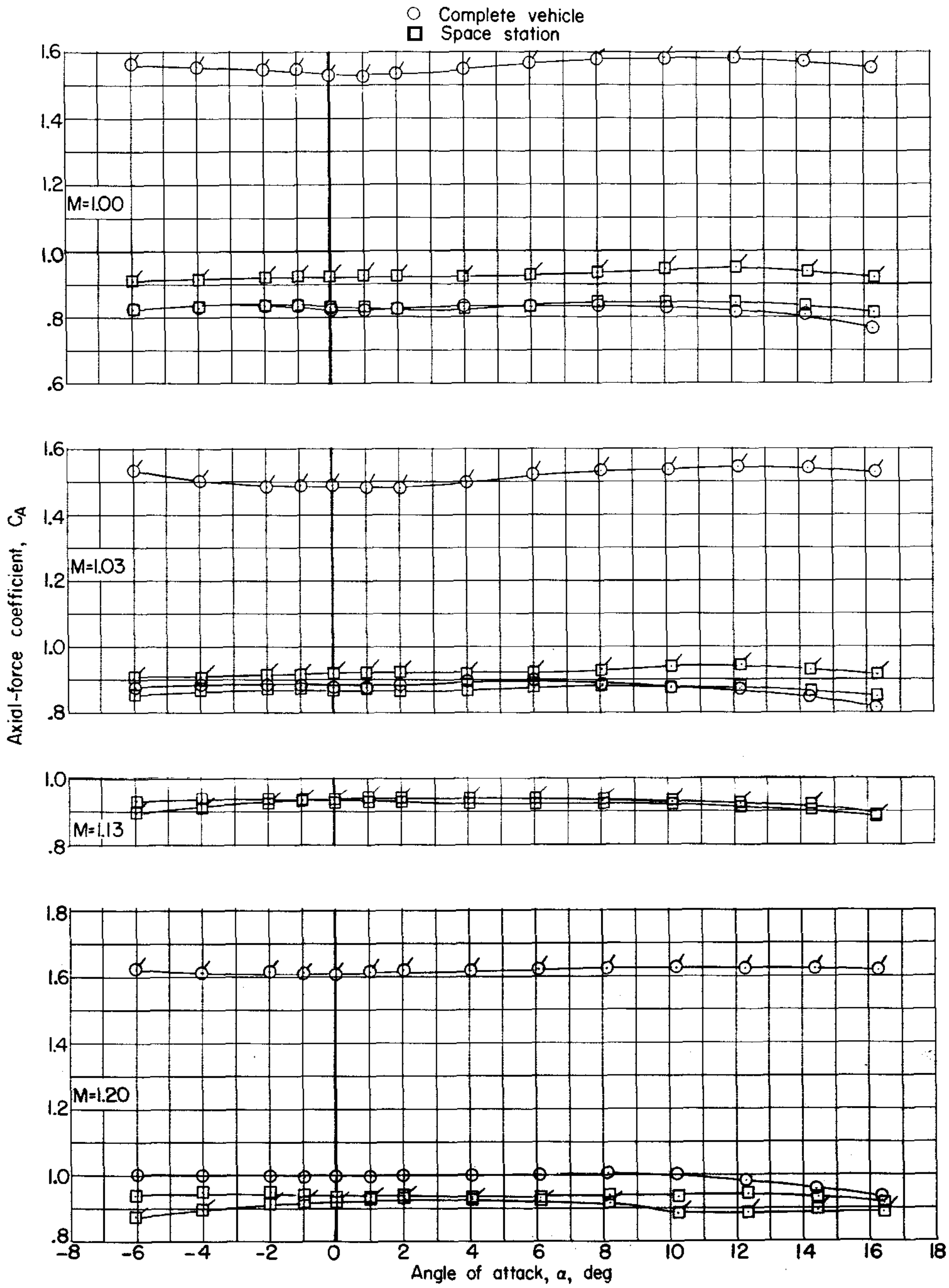

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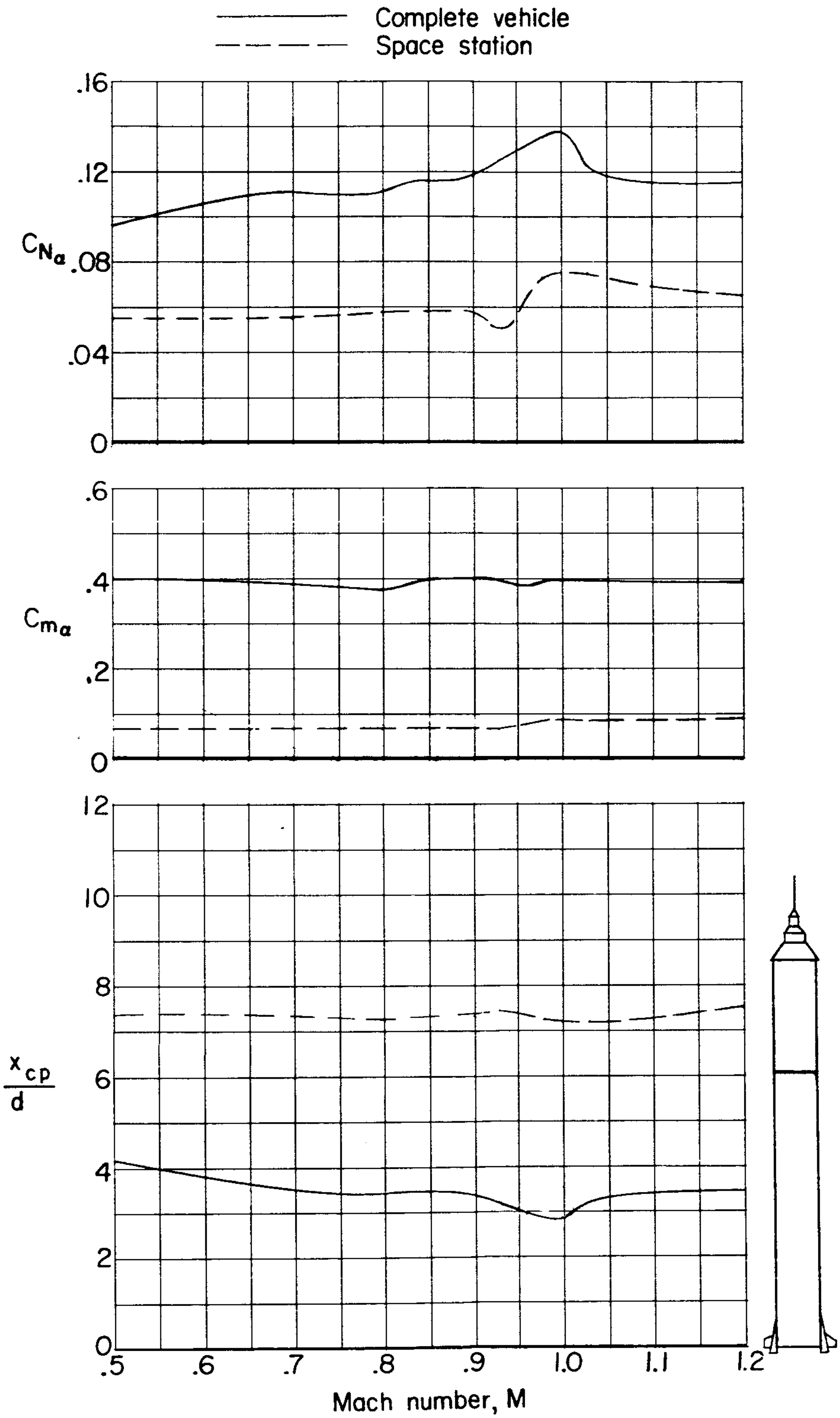


Figure 11.- Summary of static longitudinal aerodynamic characteristics.

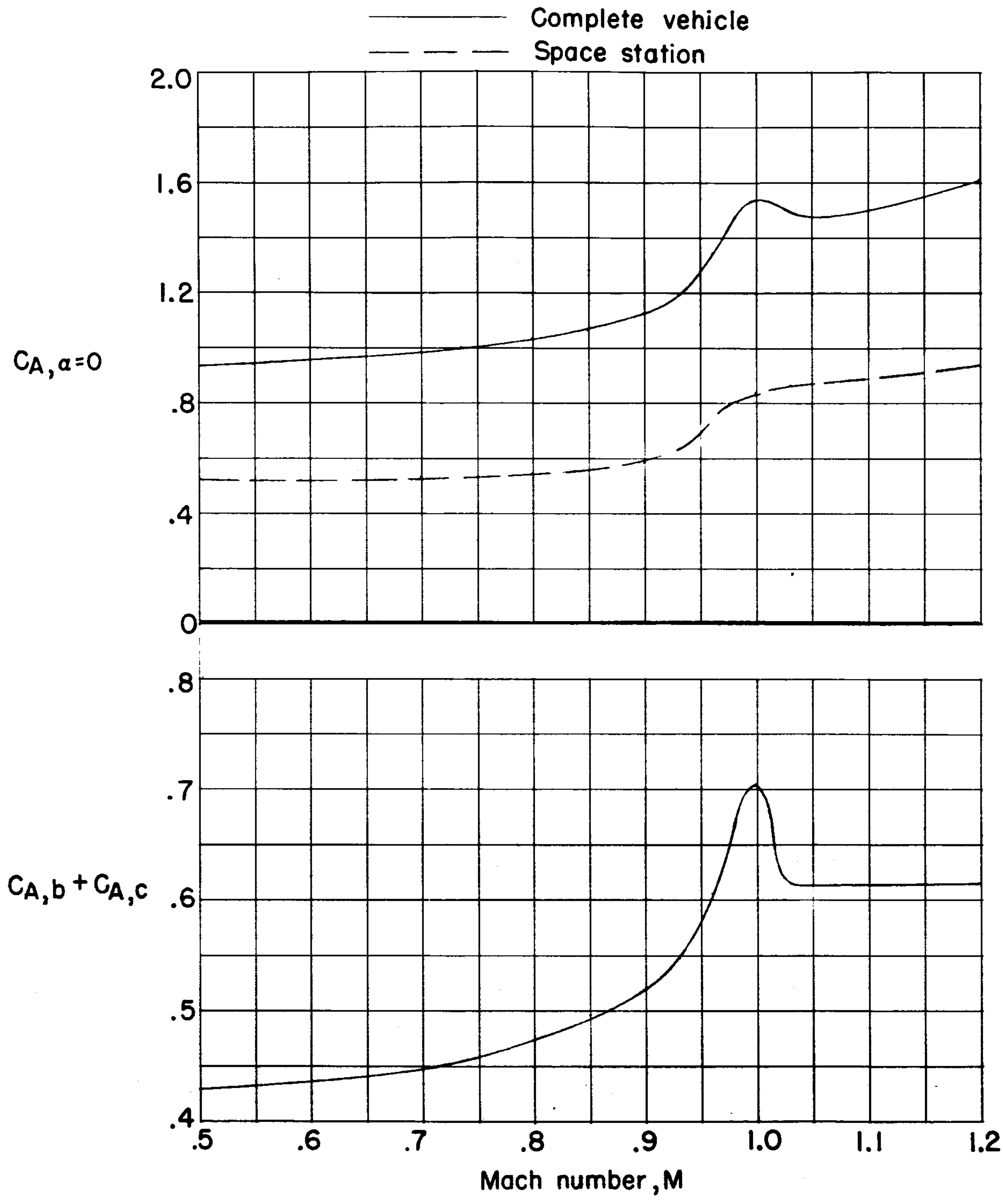


Figure 12.- Summary of transonic axial- and base-axial-force characteristics. (Complete vehicle coefficients are unadjusted for balance-cavity and model-base pressures. Space-station coefficients are adjusted for balance-cavity pressure.)

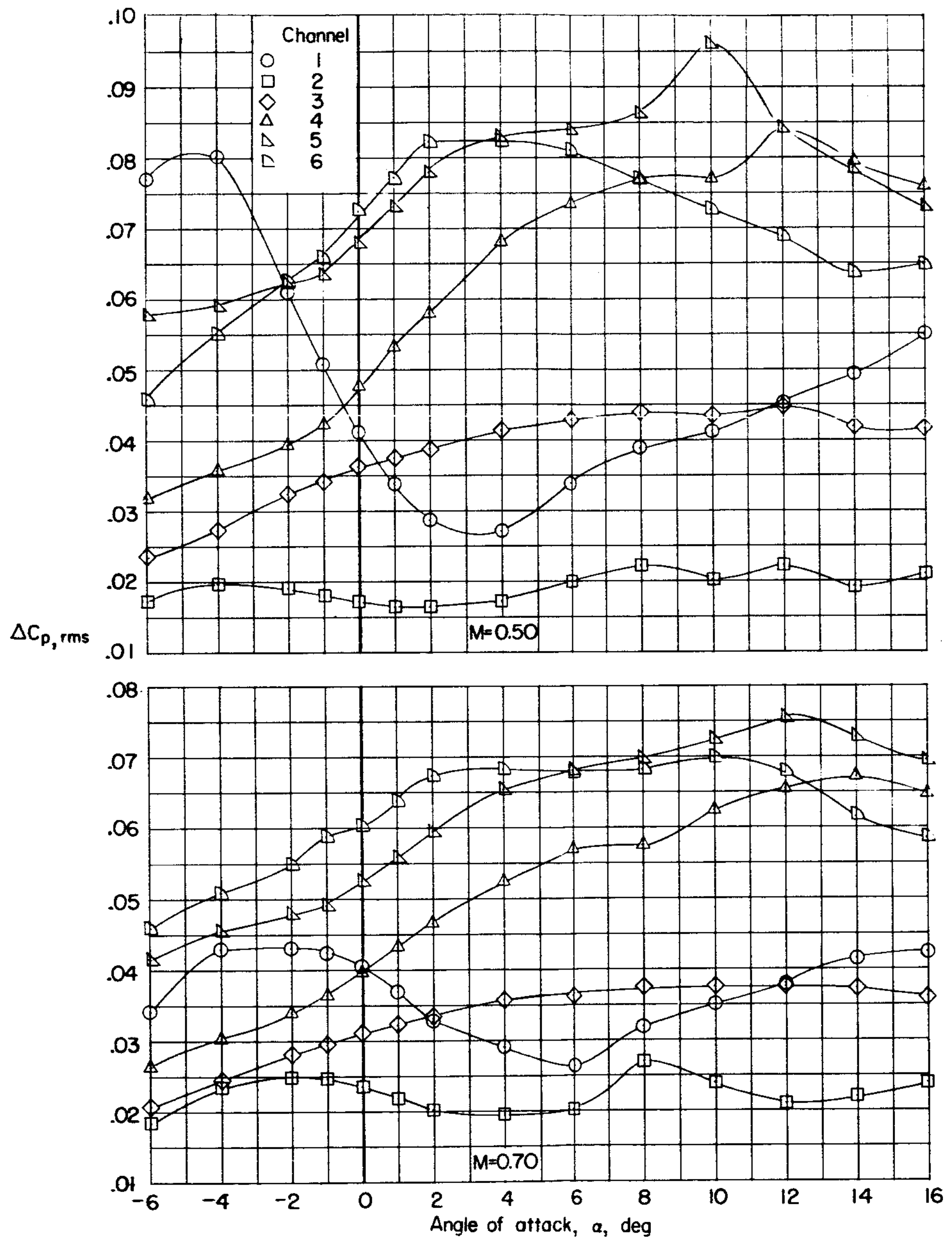
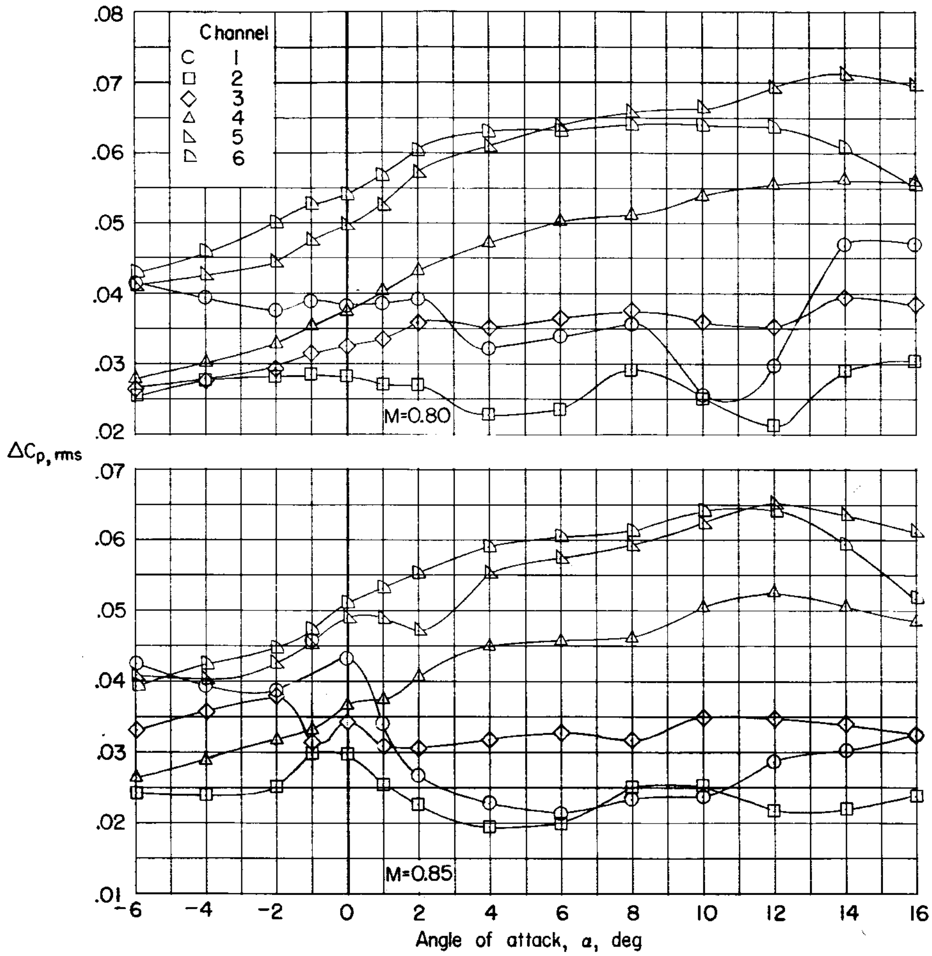


Figure 13.- Variation of root-mean-square of buffet-pressure coefficients with angle of attack for each transducer.



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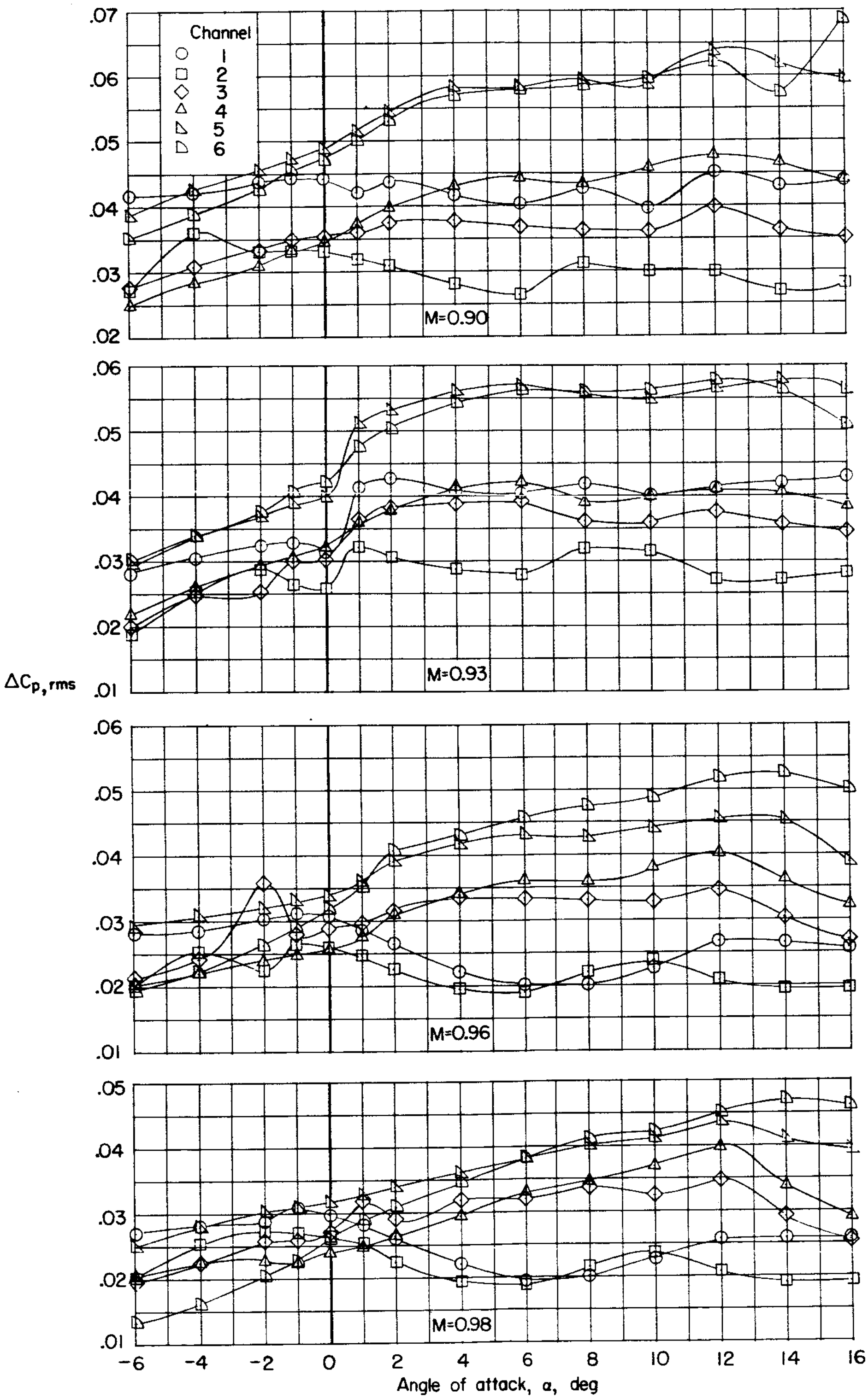

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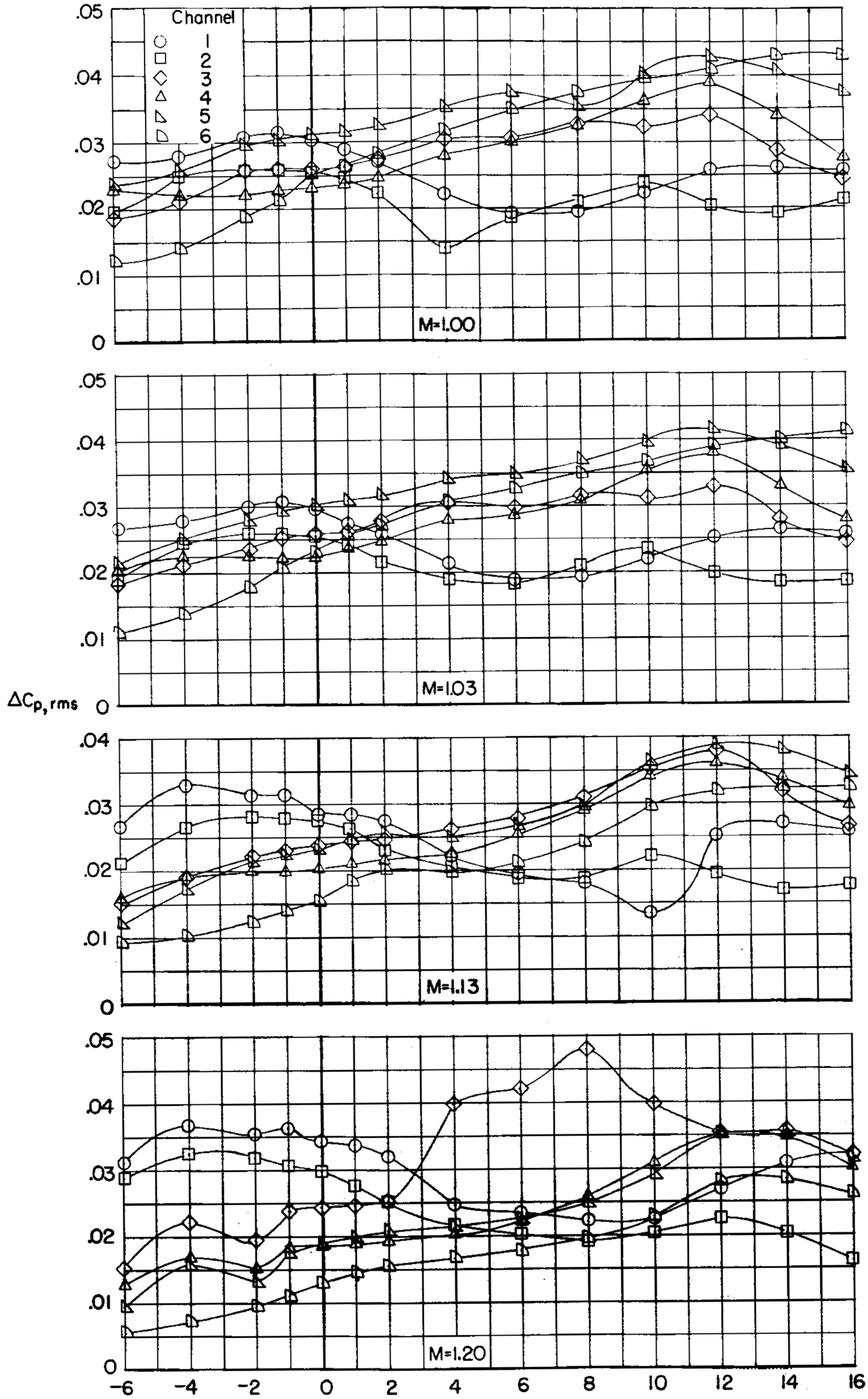

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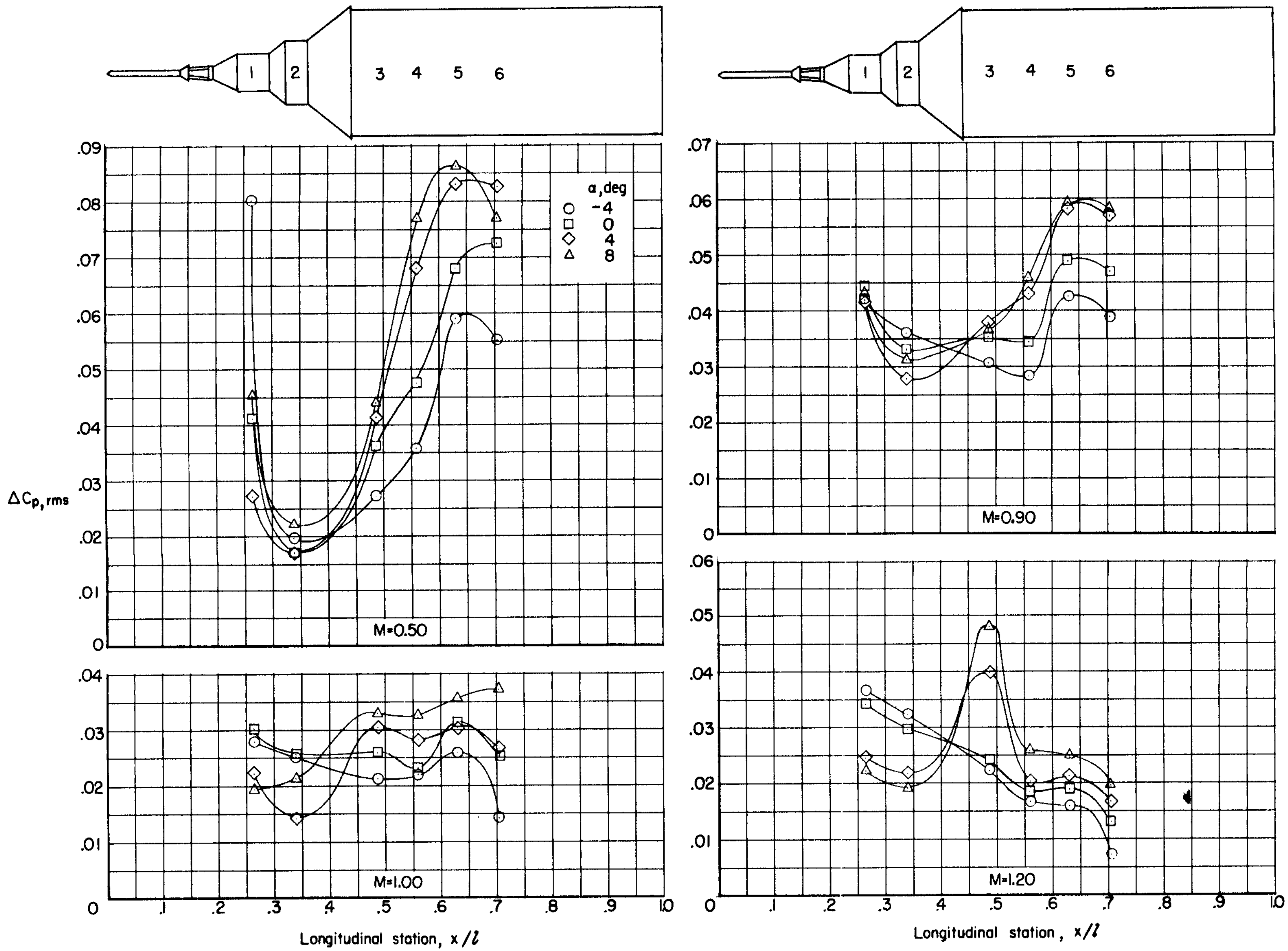

Figure 14.- Streamwise variation of root-mean-square of buffet-pressure coefficients along packaged space station.

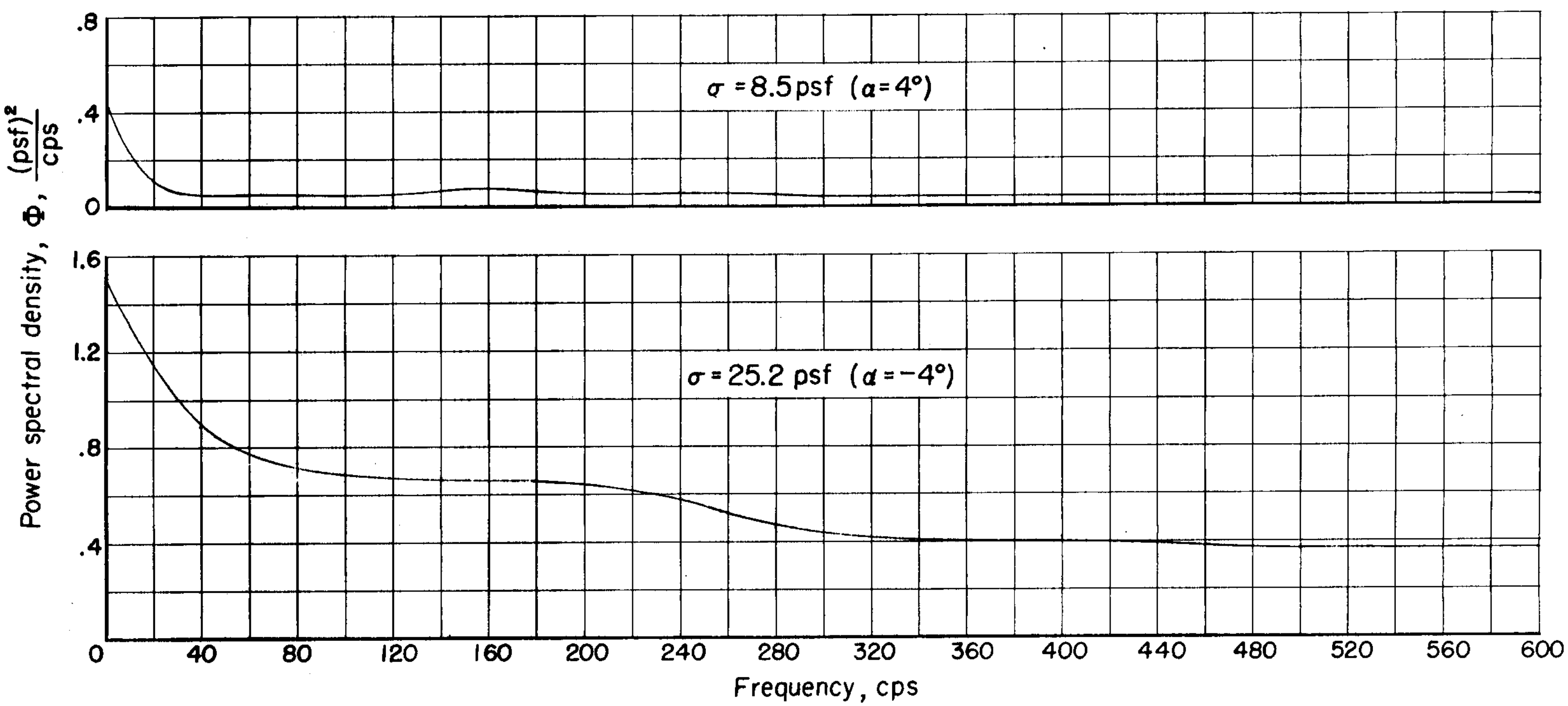

Figure 15.- Typical power spectral densities of fluctuating pressures (channel 1). Model at 1.0 atmosphere for $M = 0.50$.

NASA-Langley, 1964 L-3643